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PRECISION DRAG BALANCE OF ONE COMPONENT

7 October 1952



U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

PRECISION DRAG BALANCE OF ONE COMPONENT

By

J. M. Kendall

ABSTRACT: In the design of the drag balance of one component, considerable effort was made to design a balance capable of yielding precise measurements of drag. The novel design arrived at here eliminates static friction of all moving parts including the sting by supporting them on a system of rotating bearings. The axial force of the model applied to the sting can then be transmitted to a precision spring of iso-elastic material whose resulting stretch is measured with an accuracy of 0.0002 inch by means of a linear variable differential transformer and associated electronic equipment. Since the full scale spring stretch is 0.100 inch, the full scale reading accuracy of the measurement is 0.02 per cent. On account of the slight unsteadiness of the moving surfaces supporting the sting, the accuracy reliably achieved is slightly better than 0.1 per cent. The sting has a three-sixteenths inch diameter hole running its full length, which permits air at model base pressure to equalize the pressure in the box on the downstream end of the balance. This box contains the working parts of the balance. Since the after end of the sting is in the box which has base pressure in it, no base pressure correction must be made for the sting cross-section. The balance has been used in research projects on skin friction and base pressure.

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The drag balance, (of one component) was developed and built at NOL in order to provide a means of measuring drag force on a guided missile model in the supersonic wind tunnel with a high accuracy. The balance developed consists essentially of a moving system supported on rotating lubricated surfaces with a precision spring arranged to stretch an amount proportional to the drag force on the model and an electronic means of measuring the spring stretch with an error not over 0.00002 inches. With the balance in actual use, the measurement of drag force can be made with an accuracy of 0.1 per cent, or slightly better. The balance specifically was developed for use with a research project on the investigation of skin friction, reported in NavOrd Report 2371. Should a second balance of this type be constructed, it is suggested that consideration be given to decreasing the size of the balance, especially the diameter of the sting. The success of the balance depends primarily on the complete elimination of static friction of the moving system and the relatively simple electronic means of measuring the spring stretch with high accuracy. The balance has made it possible to carry out research work heretofore not considered to be possible. While the balance constructed is completed, it is recommended that when further research work requiring measurements of drag force with high accuracy is done, consideration be given to designing and constructing a smaller size balance. This work was sponsored by the Navy Bureau of Ordnance under task number NOL-188-52.

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ILLUSTRATIONS

Fig. 1. One component balance mounted in supersonic wind tunnel (window removed). On the table may be seen the reader and cathode ray oscilloscope used for indicating an electrical balance. Beside the oscilloscope is a precision manometer used for measuring the base pressure of the model. (Photograph G 3069 - 4).

Fig. 2. Schematic diagram of forward portion of balance.

Fig. 3. SK 304169 which shows details of forward portion of balance (Reduction in size (2:1)).

Fig. 4. One component drag balance mounted on wind tunnel sector with cone-cylinder model. (Photograph WTOP 1014)

Fig. 5. Schematic diagram of after portion of balance.

Fig. 6. SK 159075 which shows details of after portion of balance (Reduction in size (3:1)).

Fig. 7. Stationary shaft (sting) supported by a rotating bearing.

Fig. 8. Assembly of spring with clamps.

Fig. 9. Schematic diagram of electric circuit of one component drag balance.

Fig. 10. Schematic diagram of Reader.

Fig. 11. Interior of one component balance and Reader. (Photograph WTOP 1015)

PRECISION DRAG BALANCE OF ONE COMPONENT

INTRODUCTION

1. The drag balance of one component described here was developed for the purpose of making accurate measurements of drag force of models in the supersonic wind tunnel. The balance has been used in connection with investigations of base pressure and skin friction. With proper procedures and careful handling the balance is capable of measuring drag forces (in the absence of large side forces) with an accuracy of 1/10th of a per cent.
2. Essentially, the balance consists of a movable sting supported in rotating journal bearings in a wind shield with a precision spring mounted in a box on the down-stream end of the wind shield. The precision spring resists the axial movement produced by the drag force on the model, with the amount of spring extension being used as a measure of the drag force. The amount of spring extension is measured by means of a Schaevitz linear variable differential transformer (lvdt). Friction which is normally present in any device with sliding surfaces, is practically eliminated in this device by having all supports for the moving system mounted on bearings which are continuously rotated by a small electric motor.

DESCRIPTION OF BALANCE AND ACCESSORY EQUIPMENT

3. The balance and accessory equipment are shown in Fig. 1. The balance here is mounted in the supersonic wind tunnel which has the tunnel window removed, while the accessory equipment is set up out on the table beside the wind tunnel. The balance has a cone-cylinder model mounted on the sting, with the sting clamped in the wind-tunnel sector. Immediately downstream from the sector is the box of the balance, in which is located most of its working parts. An electric cable runs from the balance to the accessory equipment out on the table, along with a pressure lead tube which runs from the balance box to the manometer on the table. The manometer is used to read the base pressure of the model. Also on the table is an audio oscillator to provide the source of 600 cps voltage for the electrical system, a cathode ray oscilloscope and the reader, which when adjusted to give an electrical balance, may be read to give a measure of the drag force on the model.

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Description of Balance Mechanism

4. The forward portion of the balance, which includes the sting itself, is shown schematically in Fig. 2, which sketch is not to scale, and in Fig. 3 which is a reduced size (2:1) reproduction of the general arrangement of the same portion of the balance. The detail parts indicated by the sketch numbers scattered over the drawing of Fig. 3 are discussed in some detail in the appendix to this report. Referring again to Fig. 2, it is seen that the forward portion of the balance consists of a wind shield (outside diameter 0.750") and bearing support. This support does not rotate, but it supports the two rotating bearings whose outside surfaces are of a spherical shape (so that they have the self aligning feature), and whose inside surface is cylindrical so as to support the sting. The bearings take up all side forces on the model. These bearings are rotated by means of the forward and after drive tubes. The sting has a hole through its entire length to permit air at base pressure to flow into the box in the after portion of the balance. The portion of the sting which extends out ahead of the wind shield is used for holding the model. The drag force is transmitted from the model through the sting to the working parts in the box. The after portion of the wind shield, as may be seen in Fig. 4, increases in diameter from 0.750" to 1.024". It is along the large diameter portion only that the wind shield is clamped in the wind-tunnel sector for supporting the balance and model. Fig. 4 shows the balance clamped in the sector which has been removed from the wind tunnel.

5. A schematic diagram of the working parts located in the after portion of the balance is shown in Fig. 5. Additional details of the balance are given in the appendix. The box itself is not shown here, but may be seen in Fig. 6, which is a reduced size print of the actual shop drawing of the general arrangement. The reduction in size is about 3:1. Also the photograph of Fig. 10 shows this part of the balance. Referring again to Fig. 5, the parts of the balance which slide in the axial direction in response to a drag force on the model are shown in heavy outline. Principally, these moving parts are the sting and the yoke. The sting is connected to the yoke by means of a rubber bushing which provides a certain amount of flexibility. This flexibility is inserted in the system to avoid difficulties due to possible misalignment of the yoke and sting. The yoke is supported on three sliding bearings which do not rotate. Instead, the two shafts which run through these bearings rotate. These two shafts, as well as the big drive tube gear are all rotated by the motor. In addition to supporting the yoke mechanism, the three sliding bearings

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prevent the yoke-sting assembly from rotating with the two spherical bearings out in the forward portion of the wind shield. The motor runs approximately 2500 rpm, while the drive tubes rotate at about 400 rpm, and the two yoke supporting shafts rotate at about 1800 rpm. All of these bearings have oil holes in them packed with wool felt to keep the bearings and shafts lubricated. The lvdt is connected to the yoke by a push wire, which moves the armature in the lvdt exactly as the yoke moves. The total permitted yoke rotation is approximately 1/8 (0.125) inch. The lvdt (type C40-L) performs satisfactorily only over a total travel of about 0.100 inches, and this is the maximum motion ever used in the actual operation of the balance. When the spring is removed from the balance, the moving system consisting of the sting and yoke will move extremely freely as long as the motor is running. If the motor is shut off, static friction normal to such a non-rotating system appears at once. The amount of this friction is so great that it completely makes the balance inoperable. The lvdt armature which slides in the lvdt coil is so small and so light that the amount of friction introduced by its sliding in the coil is too small to detect. When the precision spring is in place, it is the only element to introduce any restraint on the moving system when the motor is running. Hence, all of the drag force goes to stretch the spring. On account of the zero static friction feature of this balance hysteresis effects are entirely eliminated as far as the moving system of the balance is concerned. With a precision spring of the type discussed below in the balance, the hysteresis is too small to be detected (less than about 0.02 per cent of full-scale deflection).

6. The springs are easily interchangeable. By removing two screws, in each spring clamp, as shown in Fig. 8, the assembly of spring and two clamps may be removed as a unit. A spring and clamp assembly with a different spring constant may be put in the balance to change the range of drag force to be measured. Such changing of the springs does not disturb the calibration of the springs. Since, as mentioned above, the spring is the only restraining element in the moving system, the system has an inherent simplicity which is largely responsible for the accuracy obtained with this balance.

7. The sting in the present model was made of ordinary steel. It would have been somewhat better to have made it from heat treated tool steel, such as SAE 4330, hardened to about a Rockwell C-50. Pack hardened soft steel also would do quite well. Either of these types of steel would then hold a polished surface for the bearings better than the soft steel.

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8. The self aligning bearings to support the sting take all lift and side forces on the model. These bearings are of the self aligning type so that when the sting flexes, no binding results. These bearings are made self aligning by having the outside surfaces of a spherical shape. The inside surfaces are of cylindrical shape so as to permit the sting to slide axially. When the sting flexes in response to side force or lift, the self aligning bearings change their axis of rotation so as to be parallel with the sting axis at the bearing position. The outer spherical surface, like a ball and socket joint, can take up any orientation without binding.

9. The sting and rotating shafts in the box must be free of machine and grinding marks, especially marks which run around the circumference of the sting where the bearings work. Final polishing therefore must be done with polishing paper and oil using strokes parallel with the sting axis. Any polishing marks on the sting parallel to the axis will do no harm, but those that run around the circumference sometimes will cause a noticeable stickiness in the sting action. With the motor running the sting should be just as free as though it were floating on oil, as indeed it really is when the bearings are rotating.

Functioning of Bearings

10. As mentioned above the purpose of the rotating bearing system for supporting all moving parts is to eliminate static friction. Without this feature the balance would not be successful. The rotation of the bearings and shafts causes films of lubricating oil to separate the moving surfaces from one another. As shown in Fig. 7 these films because of eccentricity of shaft and bearing actually provide fluid supports for the entire moving system of the balance. Even though the film of oil providing a support is extremely thin (order of 0.001 inch) it never permits the solid surfaces to come into contact with each other, even when the bearings are supporting a considerable load.

11. When two sliding surfaces have between them a film of oil of a definite viscosity, a resisting force is set up whose magnitude is proportional to the relative velocity of the two surfaces and whose direction is opposite to that of the relative velocity. In the case of a shaft simply rotating in a journal (cylindrical) bearing, the resulting relative motion between shaft and bearing produces a tangential force around the circumference of the shaft in the bearing. This tangential force is, of course, the so-called

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frictional torque on the bearing. Let it be assumed now that the shaft is stationary and that the bearing is rotating. The frictional torque, now tending to cause the shaft to rotate, will be resisted by whatever means is used to prevent the shaft from rotating. Now let it be assumed further, that while the shaft is prevented from rotating, it is permitted to slide axially with a slow velocity compared to the peripheral velocity of the inside surface of the bearing. The relative motion between the shaft and bearing is now helical. The force resulting from this helical motion can be broken up into two components: one component of force around the shaft (tangential) and the other component of force along the shaft (axial). The axial force has a very important characteristic which we must consider here. Its magnitude is very nearly proportional to the velocity of the axial motion, so that when the axial velocity is very low the axial force is correspondingly low, and it approaches zero when the axial velocity approaches zero. Hence for zero axial velocity we have zero axial force of resistance, and hence the static friction is completely eliminated for the axial component of motion of the shaft. In order to realize this elimination of static friction, the bearing must be rotating to maintain the oil film between the moving surfaces. Another very important practical advantage of using rotation to maintain the oil film between the moving surfaces, is that any time a dust particle gets between the moving surfaces, the dust particle is mechanically ground up by the rotation and immediately destroyed, and is thus prevented from causing any permanent sticking of the shaft in the bearing, and the condition of zero static friction is maintained. When the velocity of axial motion is not zero, the force due to this velocity is proportional to the velocity. The resistance to motion then is of the nature of a viscous resistance suitable for damping oscillatory systems. This viscous resistance is very desirable to have in the balance because it provides damping in the mechanically resonant system consisting of the mass of the model plus sting and the stiffness of the precision spring. Without this damping, any shock excitation of the resonant system would cause oscillations to persist for a considerable length of time. It is necessary for the oscillations to die down before a reading can be made, which would cause a delay in reading and hence a longer blowing time of the wind tunnel. If there is any unsteadiness in the wind tunnel, the oscillations would be continuously excited and thus would never die down, so that an accurate reading could never be made. However, with the damping described above incorporated in the balance, the balance can do a much better job of reading a drag force in the presence of unsteadiness. Hence, there would seem to be no doubt about the desirability of the damping provided by the rotating bearings.

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12. The rotating surfaces however, are never absolutely perfect themselves, and are therefore responsible for a small amount of unsteadiness. While the magnitude of this unsteadiness is of the order of a ten-thousandth of an inch when the surfaces are in fair condition, it is, nevertheless, easy to estimate the reading to a couple of hundred-thousandths of an inch in spite of this unsteadiness by getting the collapsed ellipse of the oscilloscope to a minimum. The unsteadiness is apt to become noticeable when any grit gets into the bearings, or any roughness develops on the rotating surfaces. However, if the surfaces of the sting and rotating shafts in the box are properly polished, the balance can be continuously and satisfactorily operated for at least several weeks without repolishing. The atmosphere of the wind tunnel sometimes has enough silica gel dust in it to etch the leading edges of models, but this circumstance seems to have no effect whatever on the functioning of the balance. The only attention required of the rotating surfaces after they have once been put into good condition is to oil them once or twice a day with an oil can.

Precision Springs

13. The precision springs used in this balance, a sample of which is to be seen in Fig. 8, are readily interchanged, so that for greatest accuracy it is desirable to use a spring which, with the drag force to be measured, gives a reading in the upper 2/3 of the scale. The balance seems to work quite satisfactorily with springs as weak as 100 grams force for full-scale, and as strong as 10 kilograms force for full-scale. This gives a ratio of ranges, weakest to strongest of about one to one hundred, throughout which ranges the 0.1 per cent accuracy appears to be obtainable. The precision springs used are made of iso-elastic alloy properly heat treated and have practically zero temperature coefficient and zero hysteresis. They were manufactured by John Chatillon and Sons, spring scale manufacturers, New York.

14. An alternate spring material is Ni-span-C manufactured by the H. A. Wilson Company, 95 Chestnut Street, Newark 5, New Jersey. This material made up into unheat-treated wire may be wound into a spring with the desired characteristics and brought to the finished state by a simple heat treating process. Ni-span-C springs properly made, are stated to be about the equivalent of the iso-elastic springs in regard to stable elastic properties. Music wire springs and phosphor bronze wire springs were tried, but were found to be unreliable for the degree of accuracy here required. Both of these spring materials have too high

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temperature coefficient of modulus of rigidity, with the result that small temperature changes from the calibrating temperature plainly showed up. The effect of the temperature change was to cause the calibration curve slope to decrease with higher temperature. This comes about because springs of these two materials get weaker with higher temperatures. With the recommended spring materials, is is, of course, necessary that the maximum stresses not be exceeded on penalty of altering the characteristics.

15. At least six interchangeable springs are required in a set to provide good accuracy over the range of 0.1 kg to 10 kg. Each of the springs has spring clamps fastened to both ends as shown in Fig. 8 so that by removing two screws from each spring clamp, a spring may be taken out of the balance, and a different spring with the desired stiffness may be put back into the balance by replacing the four spring clamp screws. Before this procedure can be done, it is, of course, necessary to remove and replace the cover to the box. The box must be absolutely air-tight for proper operation.

Accessory Equipment

16. The accessory equipment consists of a power supply to drive the 28-volt d.c. electric motor, a General Radio beat frequency oscillator set to 600 cps, a reader containing a second lvdt, and a cathode ray oscilloscope. The schematic diagram for all this equipment is shown in Fig. 9, Fig.10 and Fig. 11.

17. The reader containing the second lvdt is shown in Fig. 1, and consists of an ordinary 1" micrometer arranged to move the armature of the lvdt through a 2 1/2:1 step down mechanism with crossed flexure supports. One revolution of the micrometer spindle corresponds to 0.010" motion of the lvdt armature. A cylinder 2" diameter is mounted on the micrometer spindle on which is fastened the scale used for reading the position of the lvdt armature. The total permitted travel of the sting in the balance in response to a drag force is about 0.125" which is limited by stops, but of this amount, only about 0.100" of this is used. This motion is arranged to extend the precision spring an amount proportional to the drag force, and simultaneously move the armature of the lvdt an equal amount. For an electrical balance as indicated by the cathode ray oscillosograph, the armature of the lvdt in the reader likewise moves the same amount. The scale on the cylinder mounted on the micrometer spindle then rotates ten revolutions for the full scale motion of 0.100" of the sting. The scale therefore is in the form of a helix and has

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a total length of about 62.8 inches, so that a thousandth of an inch of sting deflection is represented by about 5/8 inch of scale length. The smallest divisions marked on the scale correspond to one ten-thousandth of an inch of spring extension. Hundred thousandths of an inch of spring extension can be estimated. Since the readings will usually reproduce within about 0.00003", an indicated accuracy for full scale is about 0.03 per cent. Everything included, however, it is felt that the balance is accurate to about 0.1 per cent for a reading made within the upper 2/3 of the range.

Electrical System

18. As shown by the diagram of Fig. 9, the output voltages from the two lvdt's are connected in series, and the resulting voltage, which is the vector sum of the two lvdt outputs, is fed to the "y" terminals of the Cathode ray oscilloscope (C.R.O.). The "x" terminals are connected directly to the audio beat frequency oscillator, (B.F.O.). This arrangement gives an elliptical trace of the C.R.O. spot on its screen. When the vector difference of the lvdt outputs is zero, the "y" deflection is likewise zero, and the ellipse collapses to a horizontal straight line which indicates that an electrical balance has been obtained. The electrical response of the system is practically instantaneous. In order to get the electrical balance, it is, of course, necessary to rotate the micrometer screw handle in the reader until the zero voltage difference results from the lvdt's as indicated by the collapsed ellipse C.R.O. trace. The scale reading of the micrometer may now be read for the electrically balanced condition. By referring this reading to the calibration curve, the drag force on the model in the wind tunnel for this condition is indicated.

MISCELLANEOUS EFFECTS

19. With a balance as accurate as the one here described, it is necessary to allow for the effect of the angle of attack, or rather the departure from horizontal. The moving system consisting of the model and sting acts as though it were mounted on an inclined plane. With a negative angle of attack an apparent negative drag force is produced, which effect is nothing more than $mg \sin \alpha$, where m is the mass of the model plus sting, g is gravity, and α the angle of attack. In most measurements made with the balance so far, where the greatest accuracy was needed, only zero angle of attack of the model in the wind tunnel was required. In making calibration curves, it is necessary to be very careful about the levelling of the sting. With the weakest spring in the balance, it is necessary to maintain the angle of attack during the calibration constant within 0.01° to have levelling effects negligible.

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CALIBRATION

20. The balance is calibrated by applying known forces (starting with zero force) to the sting, balancing the electrical system, and reading the micrometer scale in the reader to the nearest one one-hundred-thousandth of an inch. The curve is plotted on about six sheets of 10" X 14" linear graph paper sheets, each sheet then containing only about one sixth of the total calibration. It is necessary to use this amount of graph paper in order to spread the scale out enough to make an easy reading curve of the required accuracy. The calibration, however, is sufficiently linear that an equation of the type $F=kR$ will represent the relationship between the force F and the reading R . k , of course, depends on the spring used in making the calibration.

DISCUSSION OF EFFECTS OF LARGE SIDE FORCES

21. The effect of large side forces may be of considerable magnitude. If it were possible to make the sting and supporting wind shield of a metal with infinite modulus of elasticity (instead of the usual 30,000,000 psi for steel) the effects of the side forces could probably be eliminated. Since the sting is not infinitely rigid, it flexes as a result of side forces, and then the bearings each become inclined planes, with the result that a cross effect between side force and drag comes into operation. A pure side force, on account of flexing of the sting and wind shield, therefore produces an axial force, which shows up as a spring deflection. On this account for the base pressure and skin friction investigations the model used was made to have as little weight as possible, in order to minimize the effect of the equivalent negative lift. Here, however, the effect is essentially constant since the models used had practically zero aerodynamic lift, and the model weight of course remained constant whether the tunnel was blowing or not. In the base pressure and skin friction measurements lift and side force were therefore practically absent.

22. The balance was used with a winged guided missile model to try to measure drag in the presence of a very large aerodynamic lift. Quite consistent and reproducible results were obtained from the balance readings, even though the lift (about 60 lbs) was sometimes great enough to bend the sting (i.e., leave a permanent deformation) during some blows with a high angle of attack. While the balance readings showed up the effects of small changes

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of fin configurations, nevertheless the data obtained were of qualitative value only. In cases where the magnitude of the lift or side force are known it should be possible to make corrections for them. This, however, has not been tried yet.

PRESSURE CONSIDERATIONS

23. The sting has a hole 3/16" diameter running through it so that the pressure which occurs on the base of the model may be applied to the down stream end of the sting in the box. On this account, it is usually unnecessary to make any kind of correction to the drag force measurements due to the equivalent force pressure times sting area, since this is balanced out. The flow resistance due to the hole through the sting and due to the ducting system in the base of the model (to permit base pressure to enter the sting hole) is low enough so that pressure equilibrium is established in the box within three seconds or less after the wind tunnel blow starts. This is an important consideration for an intermittent supersonic wind tunnel. A nipple is provided on the box to which a tube may be attached to lead the box pressure (and hence the base pressure) out to a manometer outside the wind tunnel in order to measure base pressure when this measurement is required. Also a small copper tube has been run through the sting hole so that a pressure lead from a tap hole on the nose of the model can be brought out to a second manometer. In the box, the copper tube is connected to a second nipple through a short piece of flexible plastic tubing. On account of the great flexibility of the small plastic tubing, no force effects on the sting from flexing the plastic tube occur.

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APPENDIX

ADDITIONAL INFORMATION ON MOST ESSENTIAL PARTS

SK 304169 General arrangement section

SK 304159 Sting. 7/16" diameter with 3/16" hole running through entire length. The hole is to permit air from the box to flow out around the base of model so that the box pressure equals the model base pressure.

SK 123354 Retaining ring to hold in stationary bearings SK 123415

SK 123415 Hardened steel ball socket bearing, which together with SK 123352 form self aligning bearing

SK 123352 Bearing bronze bearing with spherical portion of surface for engagement with SK 123415.

SK 304166 Wind shield and bearing support 0.750" diameter

SK 304164
SK 123418 Drive tubes to rotate forward and aft self aligning bearings

SK 304167 Support tube upstream, or forward end 1.024" diameter. This portion of balance is clamped in the wind tunnel segment.

SK 159075 General arrangement-box section

SK 123341 Stationary spring support

SK 123343 Spring clamp. An identical clamp is used on both ends of the spring.

SK 123360 The assembly of the spring and its two clamps may be removed by removing the four screws which fasten the spring clamps to SK 123341 and SK 123349.

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SK 123349

Yoke. The left hand end is fastened to the sting so that when the sting is pushed to the right as by drag force, the yoke moves with the sting. The right hand end of the spring is fastened to the yoke, while the left hand end of the spring is fastened to the box through the stationary spring support SK 123341. Then, when the sting is pushed a given amount, the spring is stretched an equal amount. The yoke is supported on three bearings; each marked "bearing". The bearings in turn are supported on 3/16" diameter shafts SK 123349 and SK 123358.

SK 123345
SK 123346

Bearings. The bearings are stationary and are fastened to the box. They support the shafts SK 123349 and SK 123358. These shafts must be polished according to the same directions as the polishing of the sting in order to avoid stickiness.

G.131, G.127,
G.136, G.140

Boston gears used to couple the motor to the shafts and to the drive tube through the big gear on assembly SK 123400. The motor is marked on the drawing.

SK 123400

Assembly. This assembly consists of a big gear, a large ball bearing and the drive tube, which extends forward (to left) to drive both self-aligning bearings.

LVDT

Linear variable differential transformer (lvdt) .040L. The coils of the lvdt are fastened to the box through a bakelite support. The armature of the lvdt is mounted on a piece of wooden toothpick, the end of which extends out of the coil to the left. The left end of the toothpick is joined to a piece of .010" diameter music wire which in turn is fastened to the yoke. When the yoke moves in response to the drag force, the armature moves an equal amount. The .010" diameter music wire serves as a connector between the toothpick carrying the armature and the yoke. This connector is quite flexible in the lateral direction, but is entirely rigid in the longitudinal direction, so that there is no lost motion between the yoke and armature. The amount of friction introduced by the armature sliding on the inner surface of the lvdt is entirely negligible even compared to the weakest springs used.

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SK 304167

Support tube, down stream or aft end.

Electrical
leads

Not shown are two electrical leads for the power for the motor and four electrical leads for the lvdt. These leads are connected to small special Winchester type connectors, which have been made to be absolutely air tight.

Box

The box serves to contain all of the internal mechanism. The box must be absolutely air tight, since any leakage would cause the pressure inside to be different from the model base pressure, and hence would produce an error in the drag force indicated by the balance. Not shown are two nipples on the box. One nipple merely has a hole through it which extends to the inside of the box. A tube connected to this nipple and run to a manometer outside of the wind tunnel permits box pressure, and hence model base pressure, to be measured. The other nipple is connected to a small plastic tube (1/16" inside diameter) which is very flexible. The other end of the plastic tube connects to a copper tube 1/16" inside diameter. The copper tube runs through the hollow sting forward to the model. The nose pressure or other pressure on the surface of the model may be measured by means of this tube.

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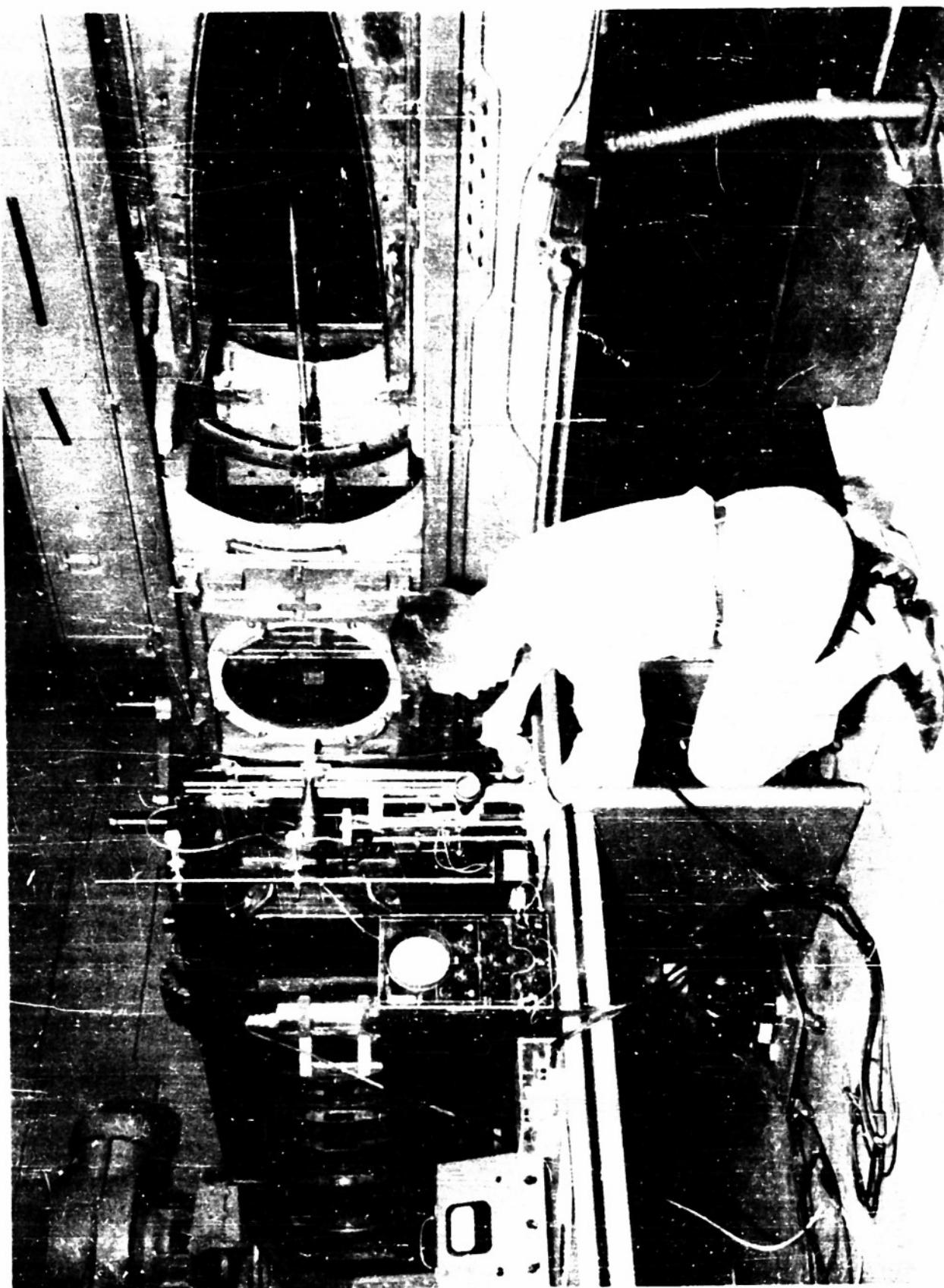


FIG. 1

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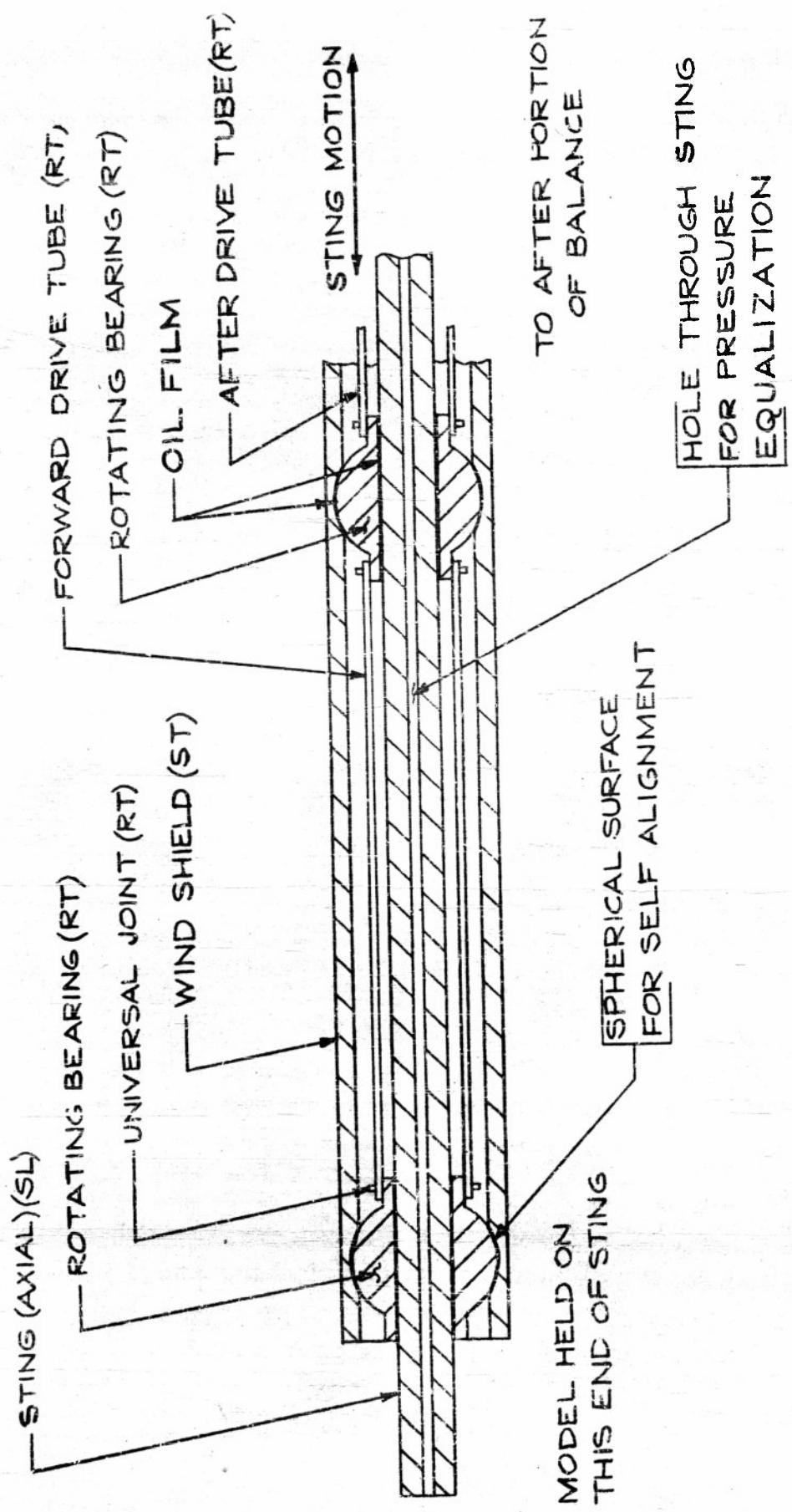


FIG. 2 SCHEMATIC DIAGRAM OF FORWARD PORTION OF BALANCE

ST-STATIONARY

SL-SLIDES

RT-ROTATES
NOT TO SCALE

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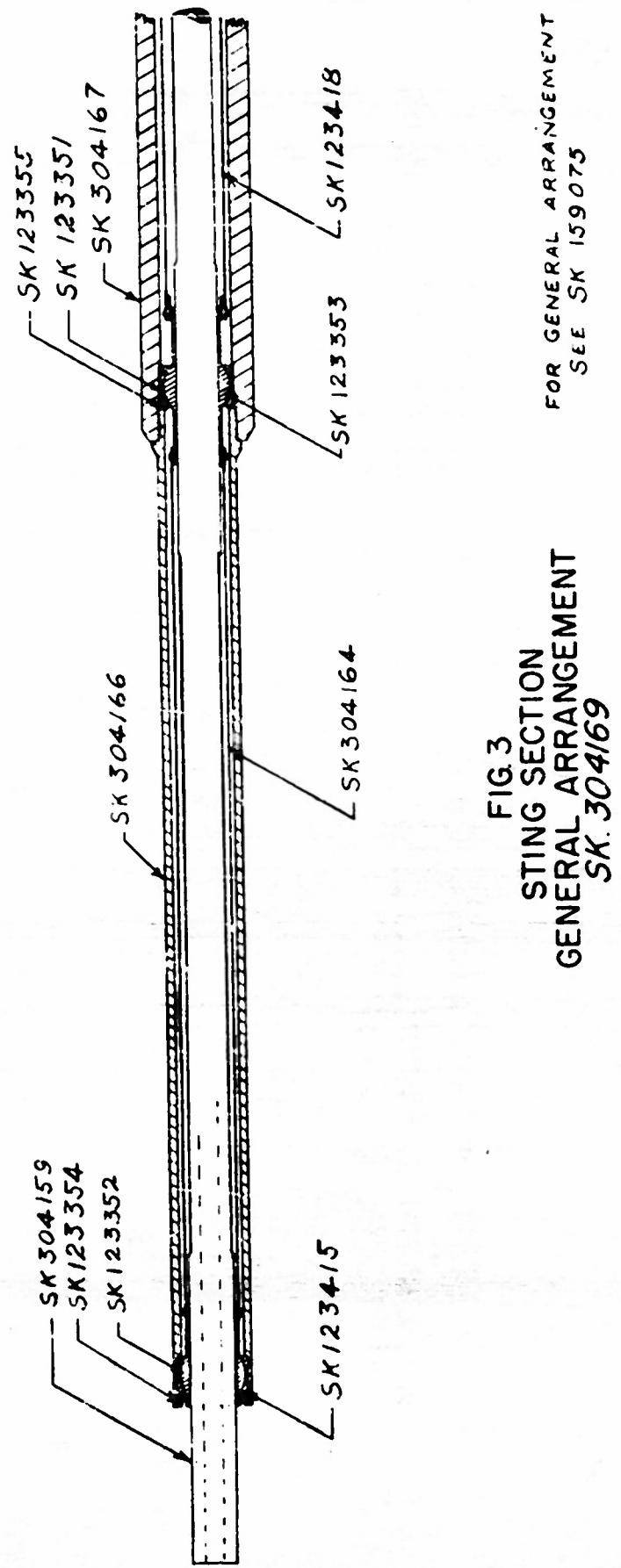


FIG. 3
STING SECTION
GENERAL ARRANGEMENT
SK. 304/69
SEE SK 159075

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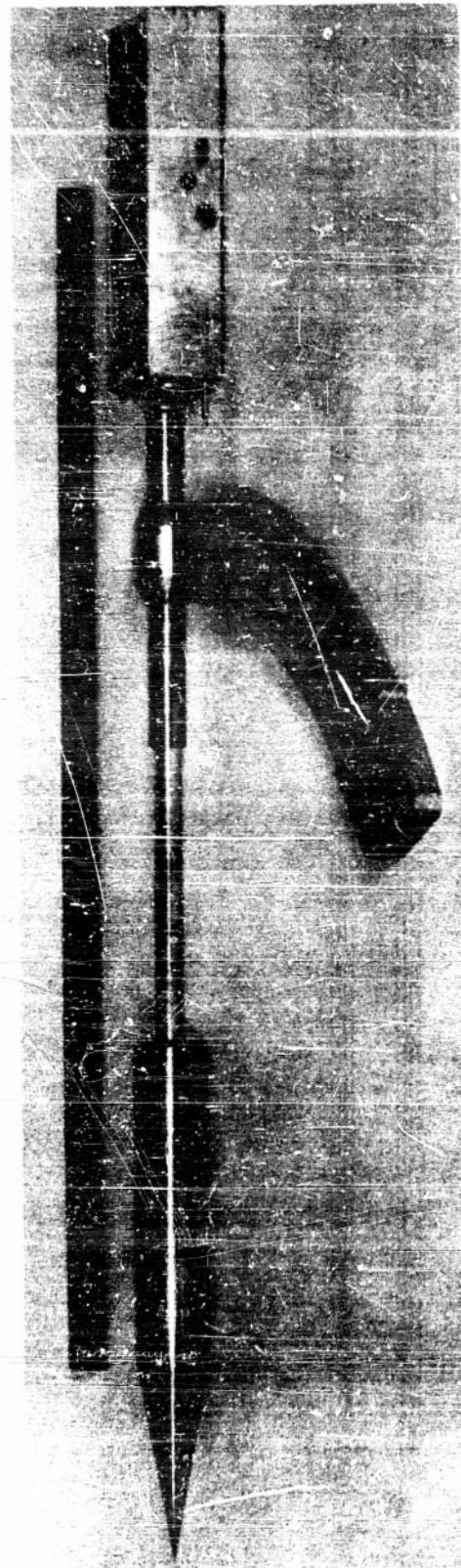


FIG. 4

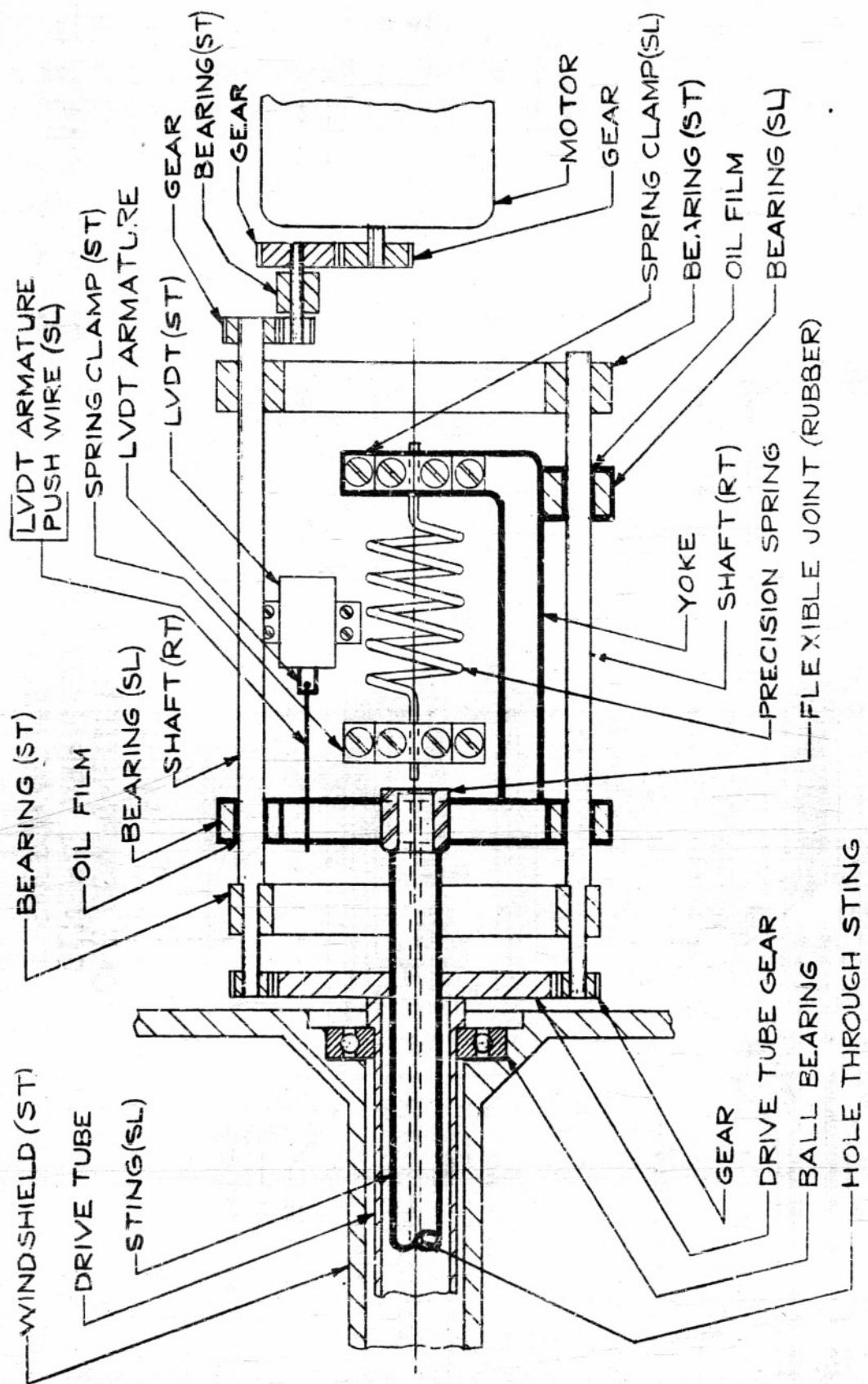


FIG. 5 SCHEMATIC DIAGRAM OF AFTER
PORTION OF BALANCE
HEAVY OUTLINES INDICATE MOVING SYSTEM
ST-STATIONARY
SL-SLIDES
RT-ROTATES
NOT TO SCALE

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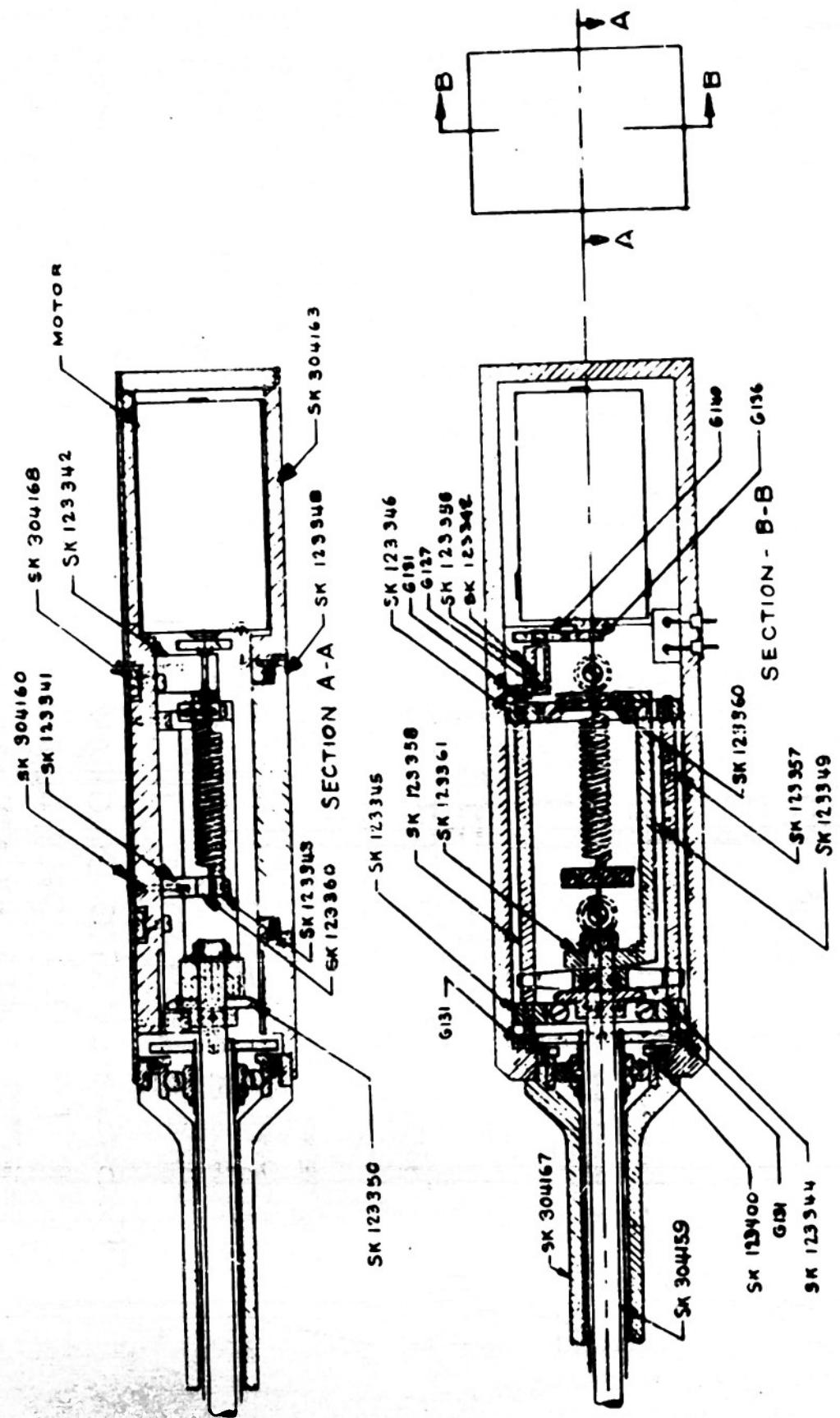


FIG. 6
ONE COMPONENT BALANCE
GENERAL ARRANGEMENT
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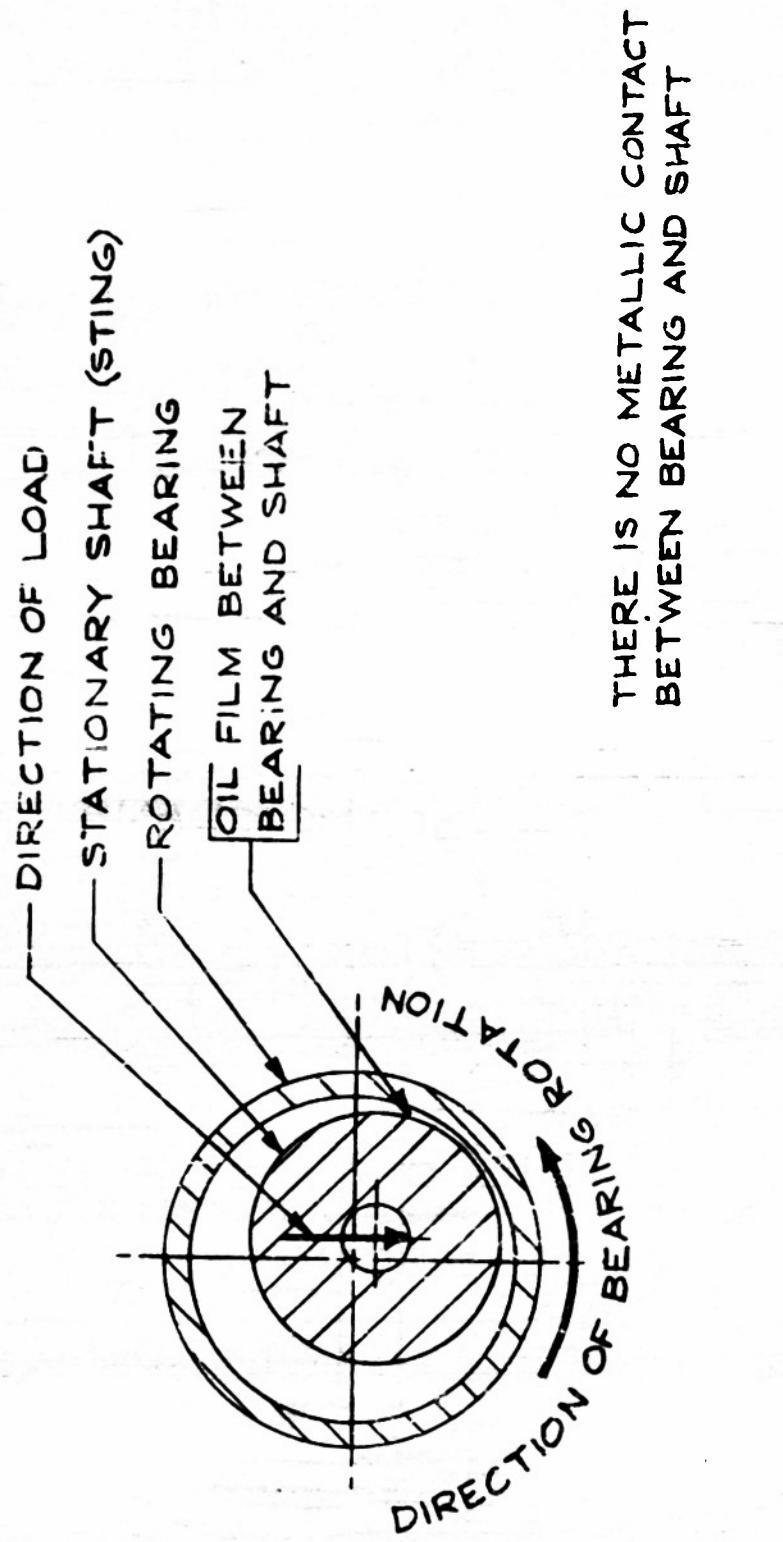


FIG. 7 STATIONARY SHAFT (STING) SUPPORTED BY ROTATING BEARING

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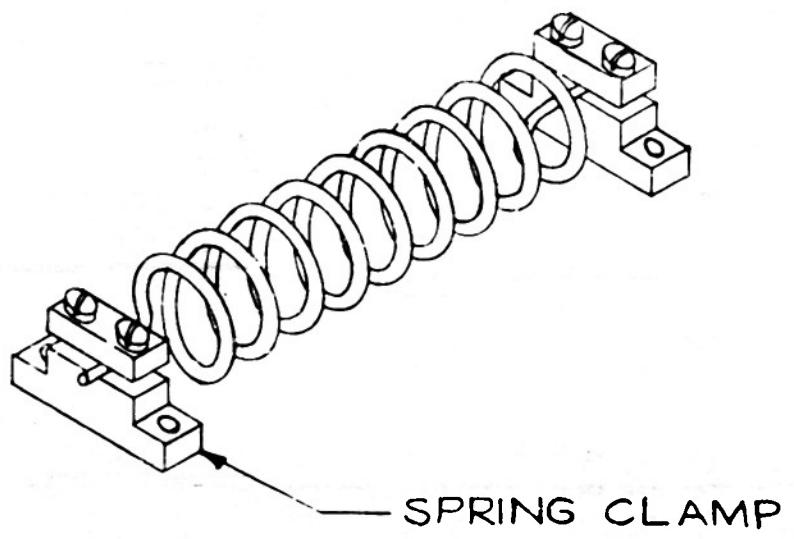


FIG. 8

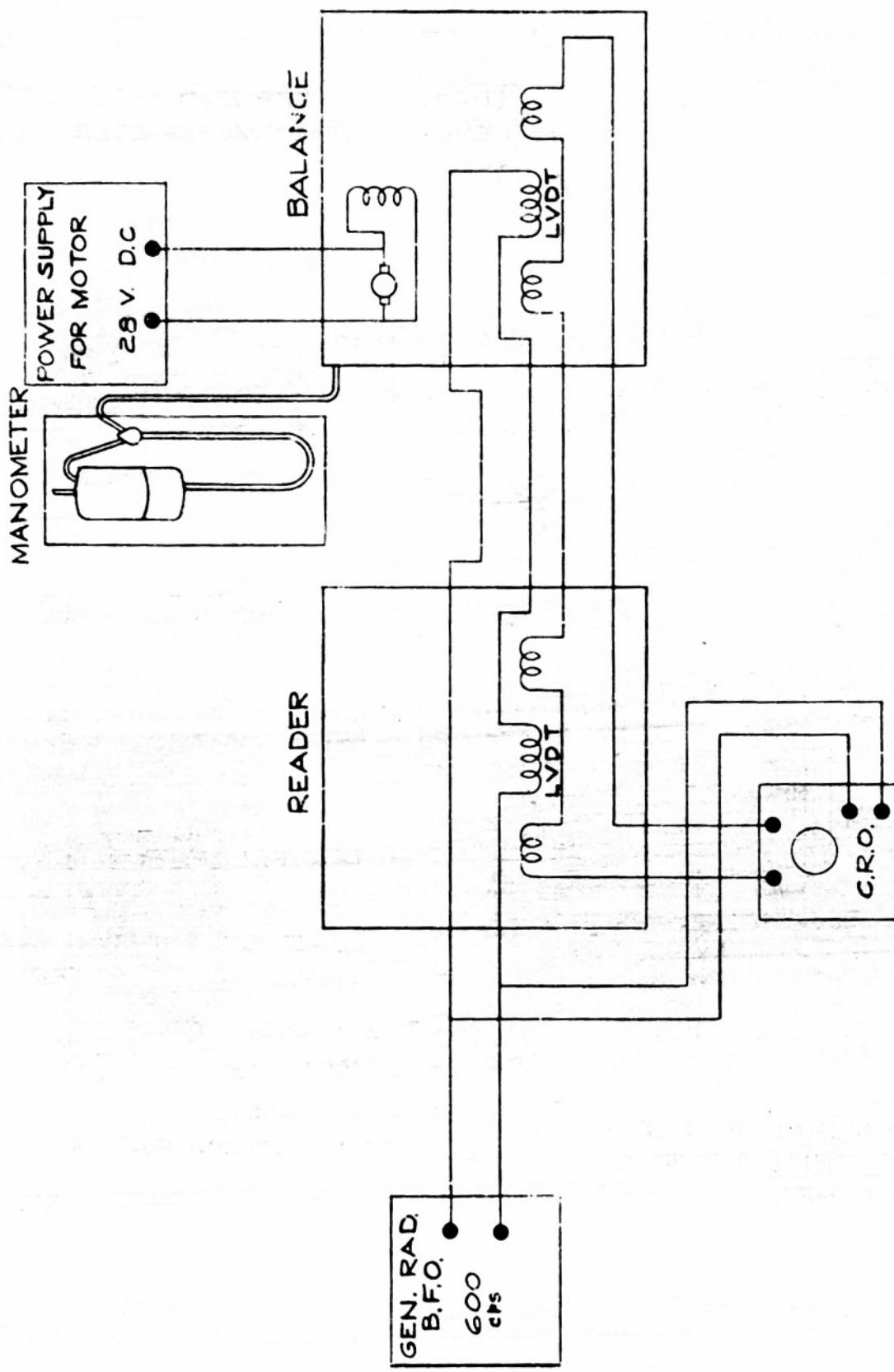


FIG.9 SCHEMATIC DIAGRAM OF ELECTRIC CIRCUIT ONE COMPONENT BALANCE.

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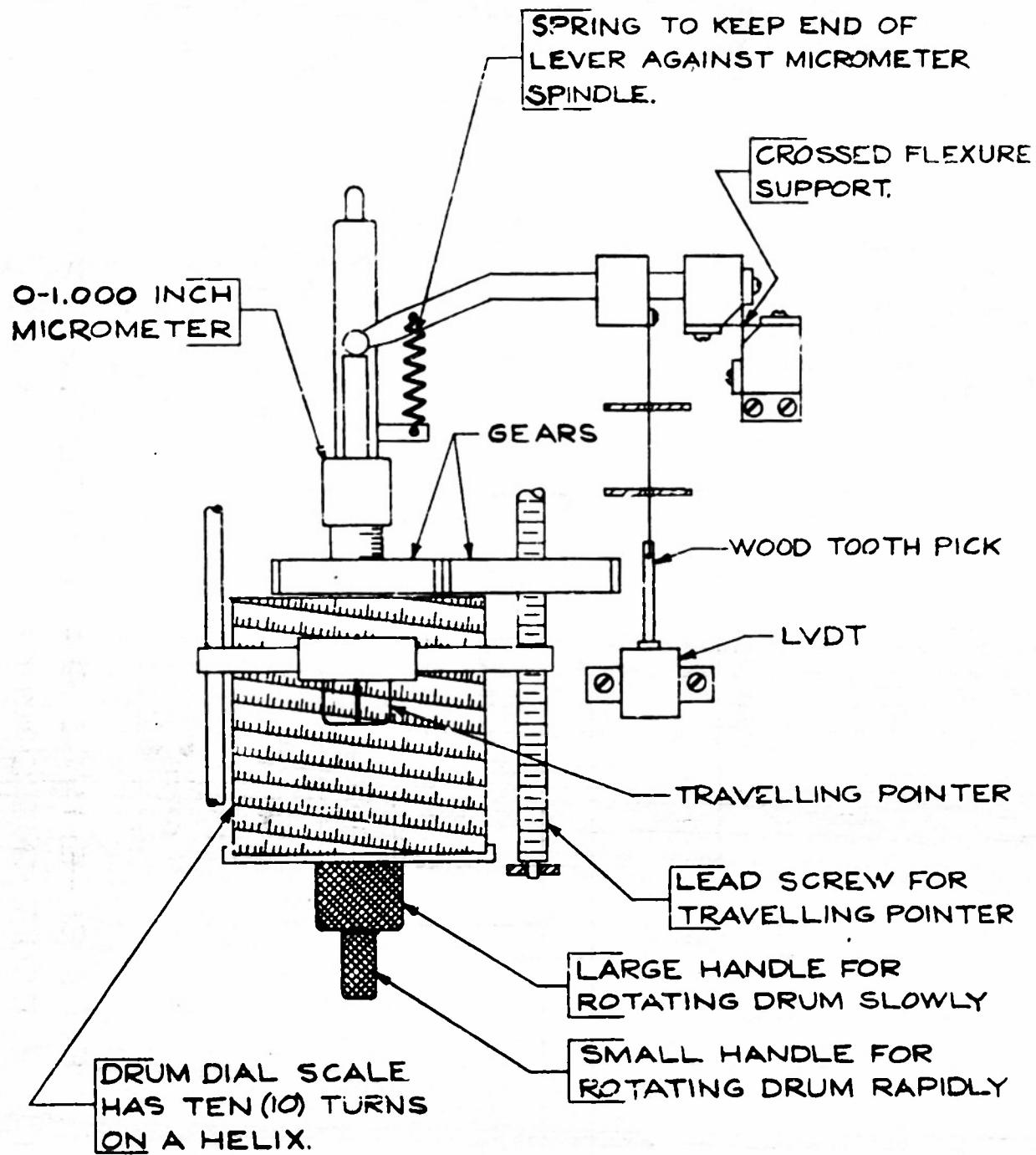


FIG. 10 SCHEMATIC DIAGRAM OF READER

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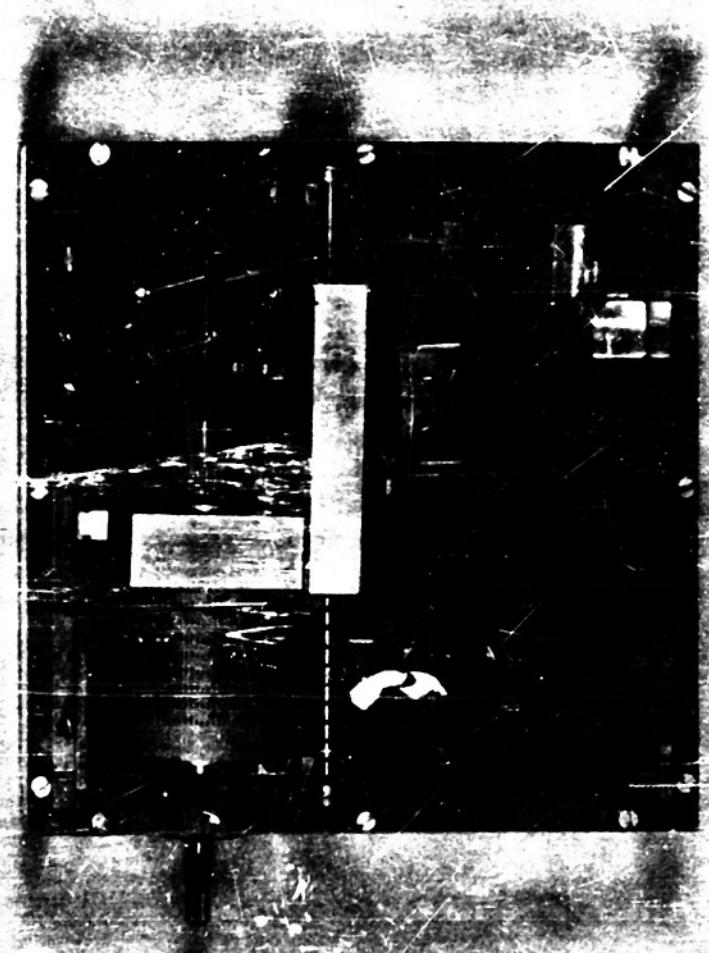


FIG. 11

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